R&D for 0vbb and neutrino mass (report from morning neutrino-properties session)

Ben Monreal

Huge amount of activity in 0vbb now and soon

2015	2016	2017	2018	2019	2020	2025

?—Ricochet—>

?—COHERENT—> ?—enriched CUORE, light—->

<————————-CUORE—————————51/130 meV—->

<——MajoranaDemonstrator—> <—- Majorana/GERDA fusion——————-

———EXO-200—> ?—-nEXO —7-18 meV—-? ?—- + Ba—-?

NEXT-WHITE ?— NEXT-100kg—- ?— NEXT + Ba tag—-?

Kamland-Zen ?—-Kamland2 upgrade towards 20 meV? —-?

SNO+ Te-loaded scint ?—- Theia aim for 15meV—->

SuperNEMO 1M <—— SuperNEMO buildup—>

<————- KATRIN—200 meV—>?—-TOF runs?——>

—-Project 8 R&D ——> ?—- Project 8 100 meV ————-— Project 8 atomic—-?

—-163Ho R&D ——> ?—- 163Ho scaleup ~1 eV ————-?————-163Ho 0.1 eV—-?

*These are not official numbers, please see the talks

- Large experiments on clear paths
  - CUORE, Majorana = 0vbb search
  - SuperNEMO = 0vbb search/characterization
  - KATRIN = tritium endpoint search
  - A few years of "known" construction/operations
- Large experiments in transition
  - NEXT-WHITE (NEXT-100), EXO-200 (nEXO)
  - Majorana/Gerda merger/downselect
- Creative hardware repurposing
  - Ricochet, Cr51, COHERENT = coherent/magnetic
  - Kamland-Zen, SNO+ = add 0vbb to former solar exp.
- R&D projects doing something new
  - ASDC/Theia, NuDot = new LS-0vbb ideas
  - Project 8, Holmes/Echo/NuMecs = beta endpoint

- Large experiments on clear paths

  Cryo HPGe
  - CUORE, Majorana = 0vbb search

  tracking
  - SuperNEMO = 0vbb search/characterization
  - KATRIN = tritium endpoint search classical spectrometer
  - A few years of "known" construction/operations
- Large experiments in transition

  Xenon TPCs
  - NEXT-WHITE (NEXT-100), EXO-200 (nEXO)
  - Majorana/Gerda merger/downselect HPGe
- Creative hardware repurposing

  CDMS LZ Majorana
  - Ricochet, Cr51, COHERENT = coherent/magnetic

  Xe in LS Te in LS
  - Kamland-Zen, SNO+ = add 0vbb to former solar exp.
- R&D projects doing something new

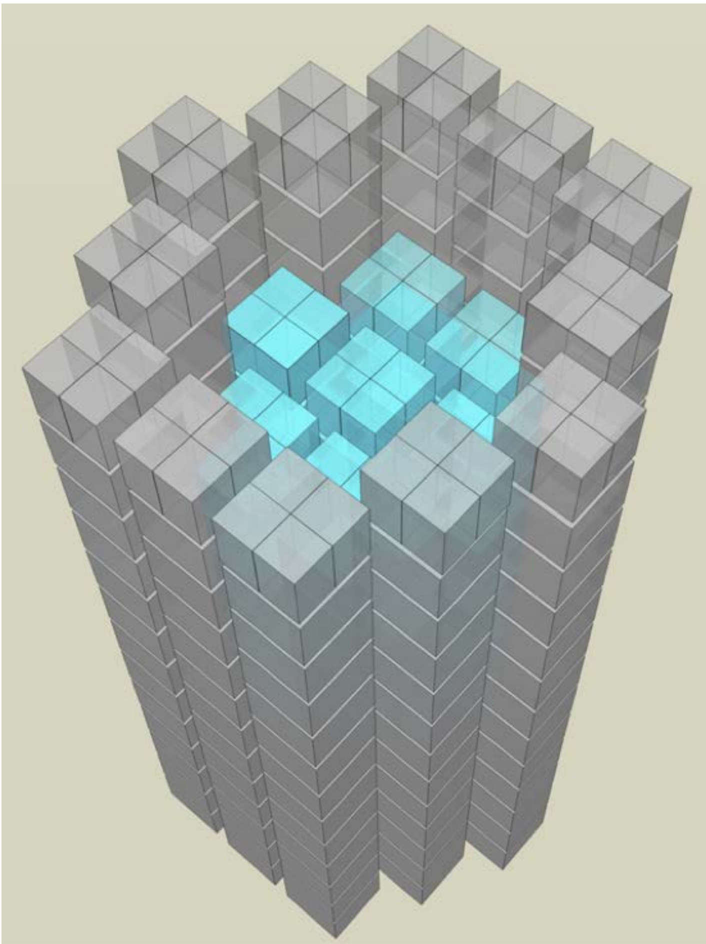
  WbLS Quantum dot LS + LAPPDs
  - ASDC/Theia, NuDot = new LS-0vbb ideas
  - Project 8, Holmes/Echo/NuMecs = beta endpoint

  classical spectrometer microcalorimeters

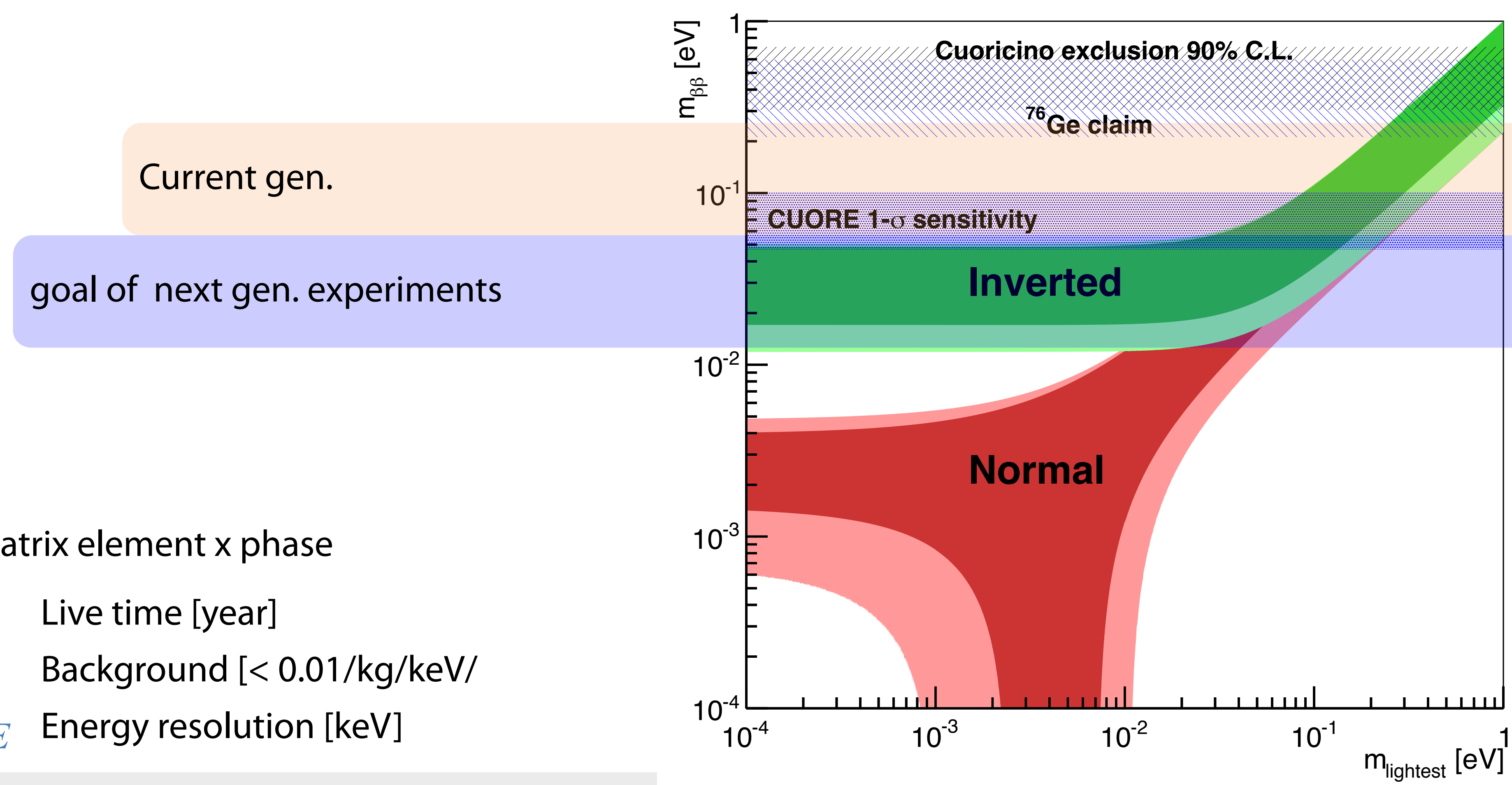
0vbb

- Very promising routes to edge of inverted-hierarchy sensitivity in next 5 years.
- Very promising routes to cover whole inverted hierarchy in few-ton-scale experiments now being proposed/designed
- Some dreams of moving deep into the normal hierarchy

Beyond CUORE: ^{130}Te Enrichment



- Natural next step for CUORE
  - Increase # of parent nuclei, not the detector mass (# of background events)
- ^{130}Te enrichment is relatively cheap at $17K/kg
  - Compared to ^{76}Ge enrichment at $100/g
- 500 gram of enriched ^{130}Te metal is sent to SICCAS for enriched crystal growth.

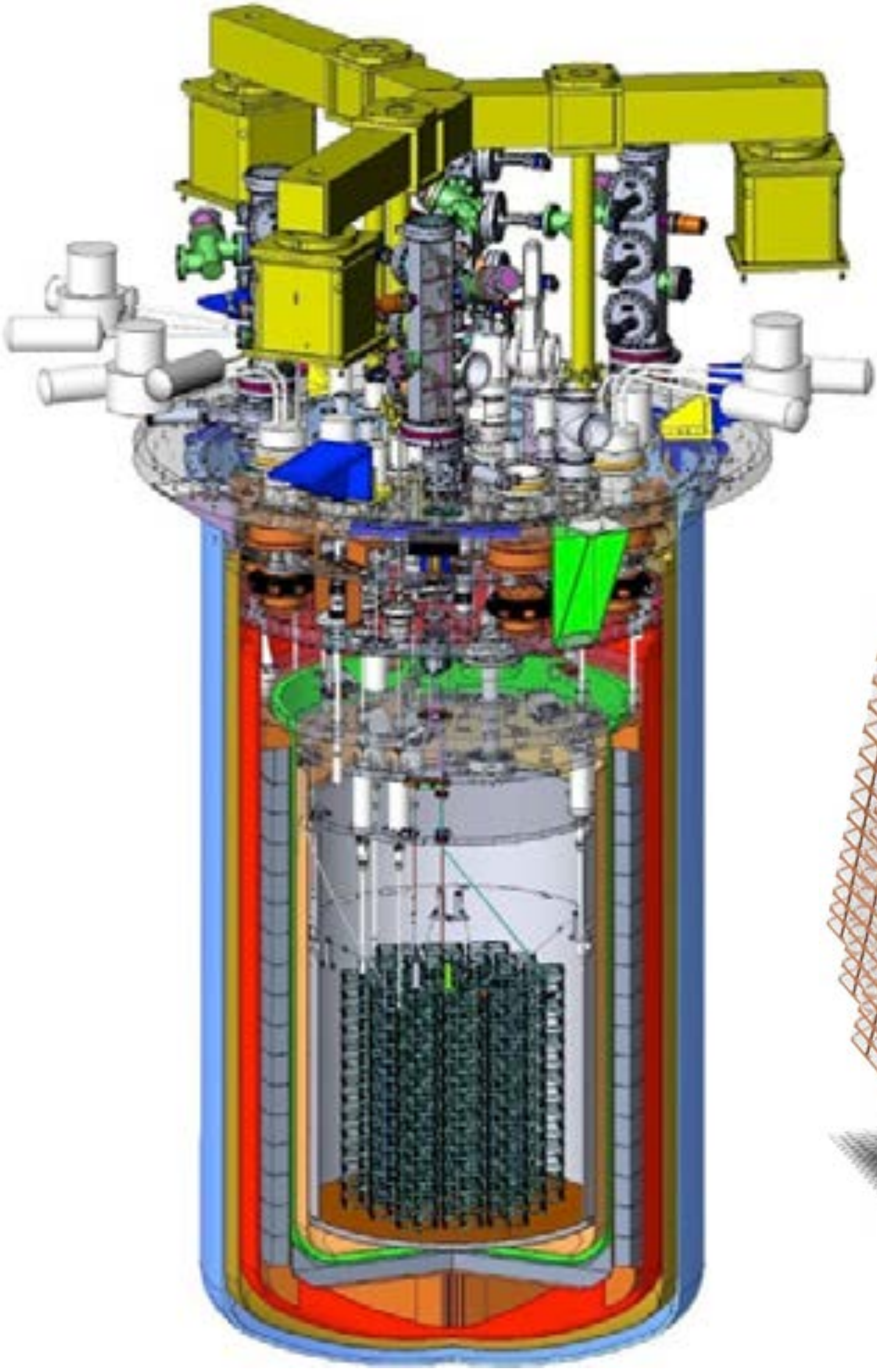


$$m_{\beta\beta} \sim \frac{m_e}{\sqrt{F_N \cdot \varepsilon \cdot \eta \sqrt{\frac{M \cdot t}{b \cdot \delta E}}}}$$

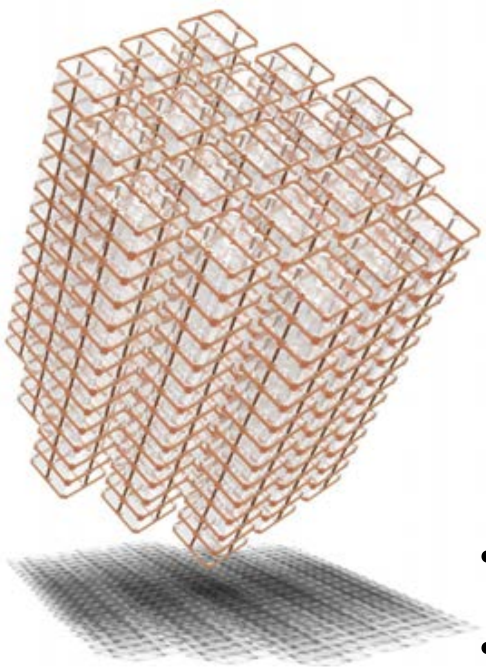
F_N	Nuclear figure of merit: nuclear matrix element x phase		
ε	Detection efficiency	t	Live time [year]
η	Isotopic abundance	b	Background [< 0.01/kg/keV/
M	Detector total mass [kg]	δE	Energy resolution [keV]

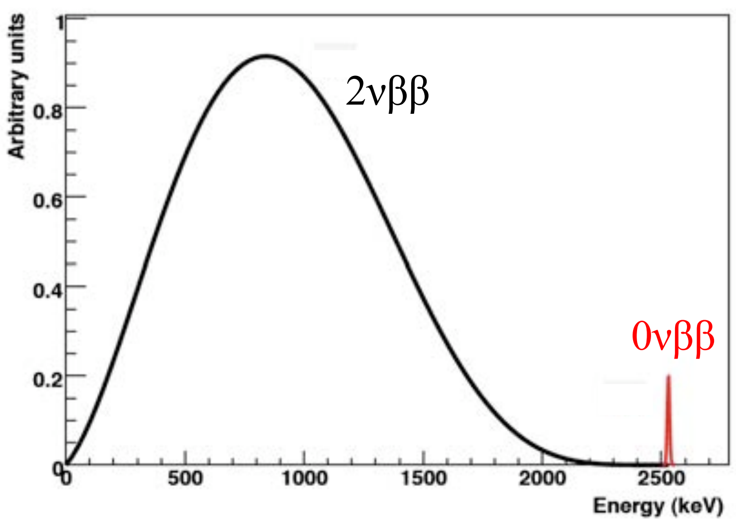
CUORE

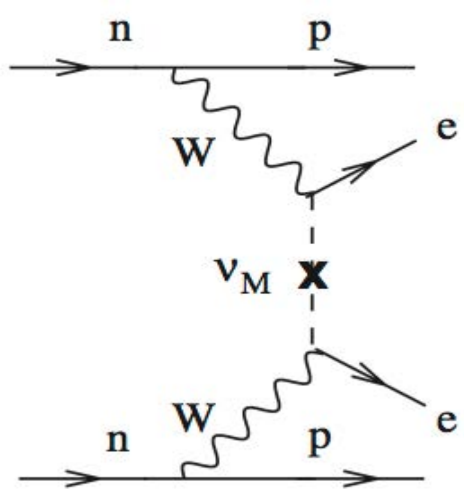
Cryogenic Underground Observatory for Rare Events



- 988 TeO_2 crystals run as a bolometer array
  - 5x5x5 cm^3 crystal, 750 g each
  - 19 Towers; 13 floors; 4 modules per floor
  - 741 kg total; 206 kg ^{130}Te
  - 10^{27} ^{130}Te nuclei



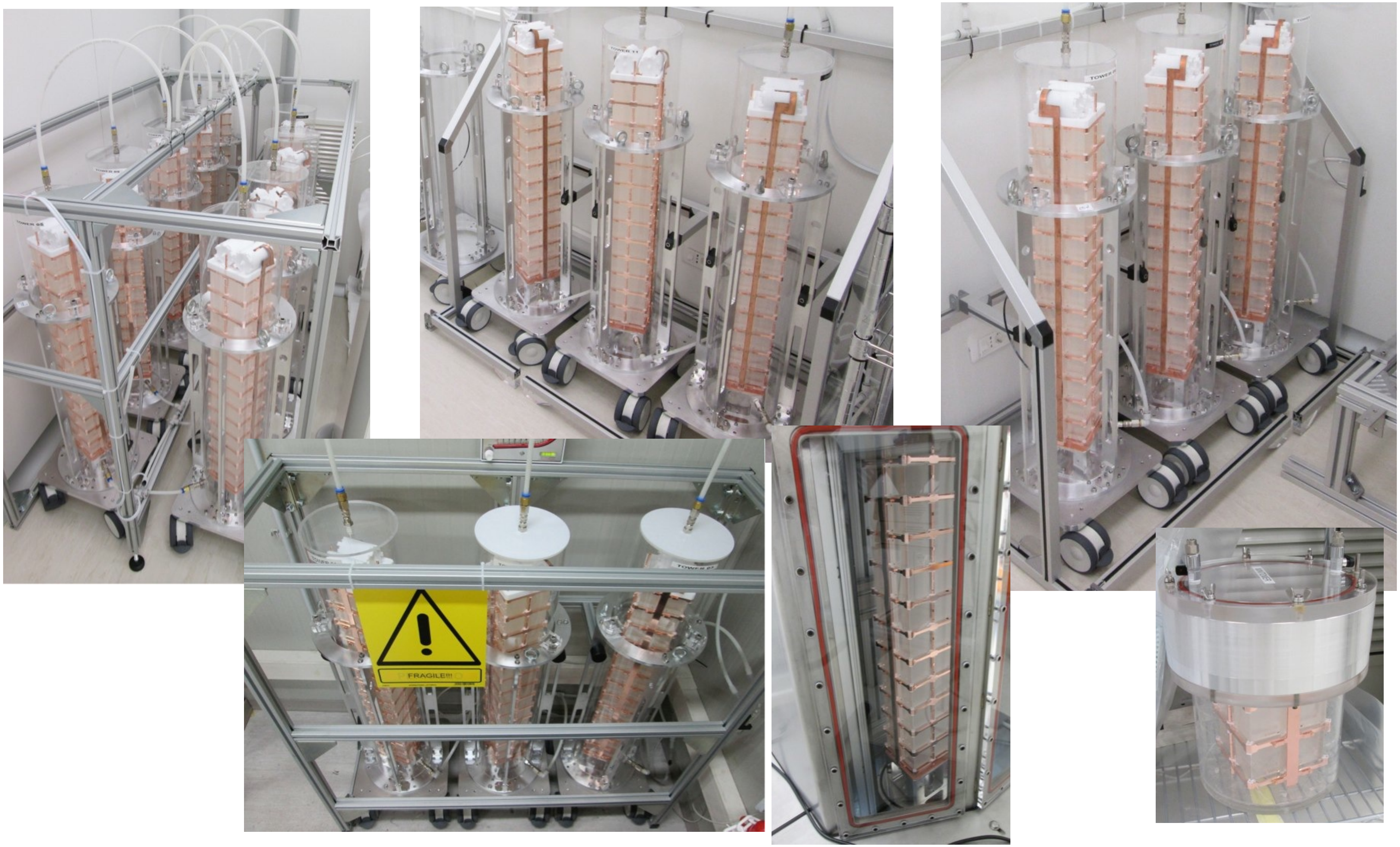




- Excellent energy resolution of bolometers
- New pulse tube dilution refrigerator and cryostat
- Radio-pure material and clean assembly to achieve low background at region of interest (ROI)

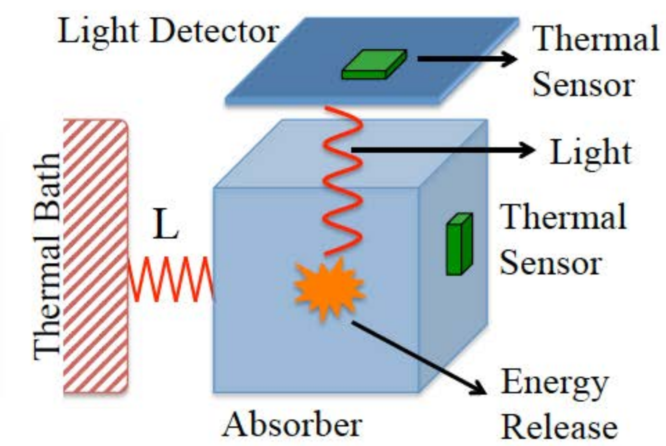
CUORE Detector Towers

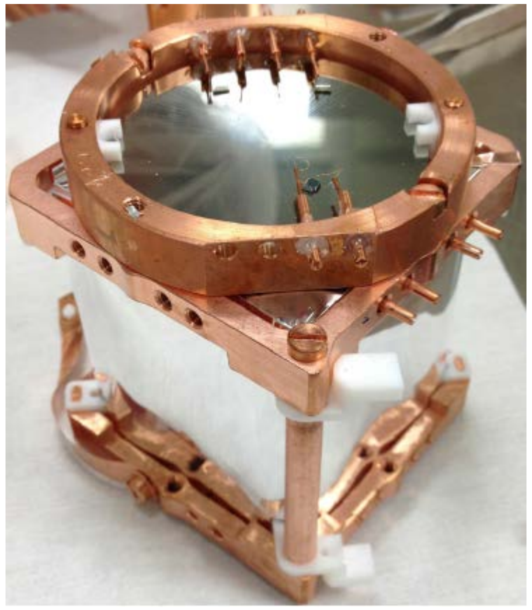
Assembly of all 19 towers is complete

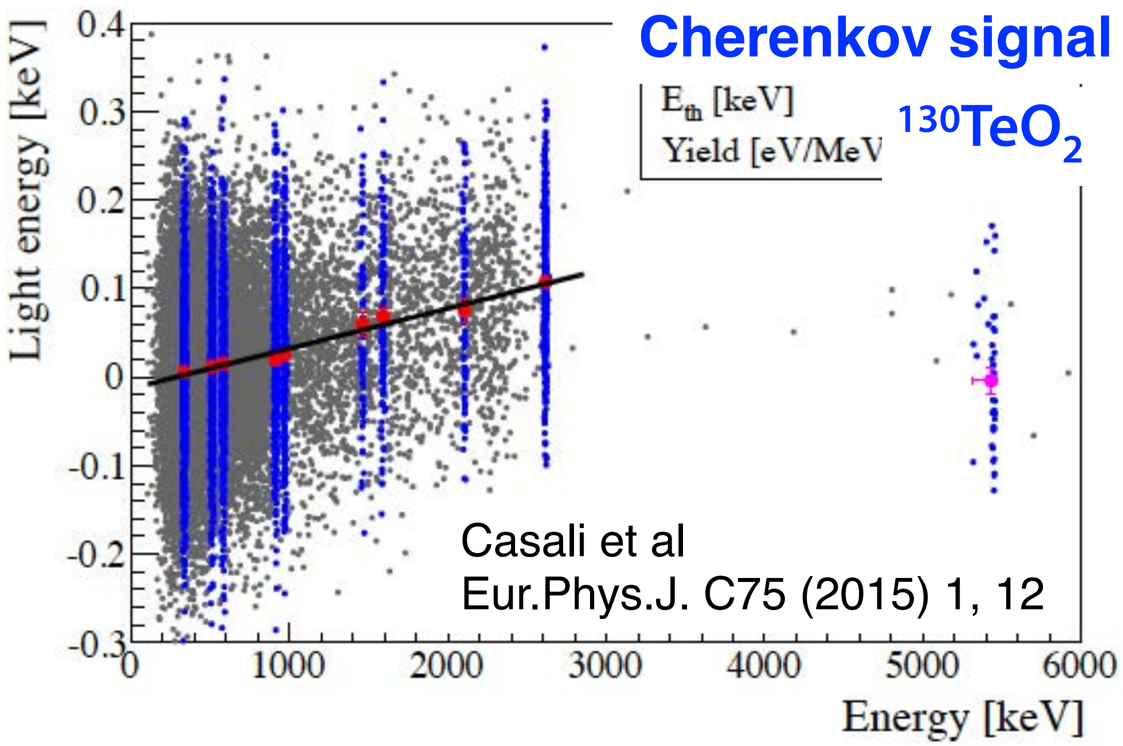


Beyond CUORE: Particle ID with Light Detectors

phonon+photon

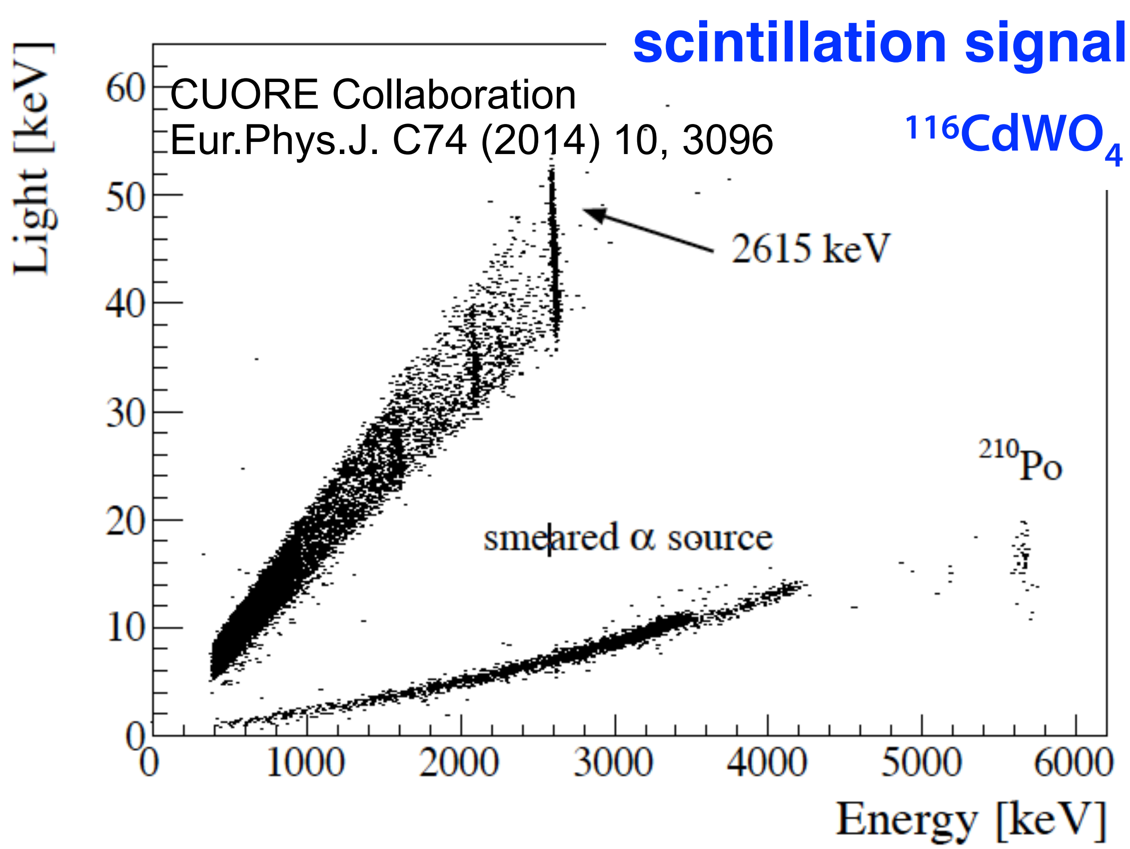




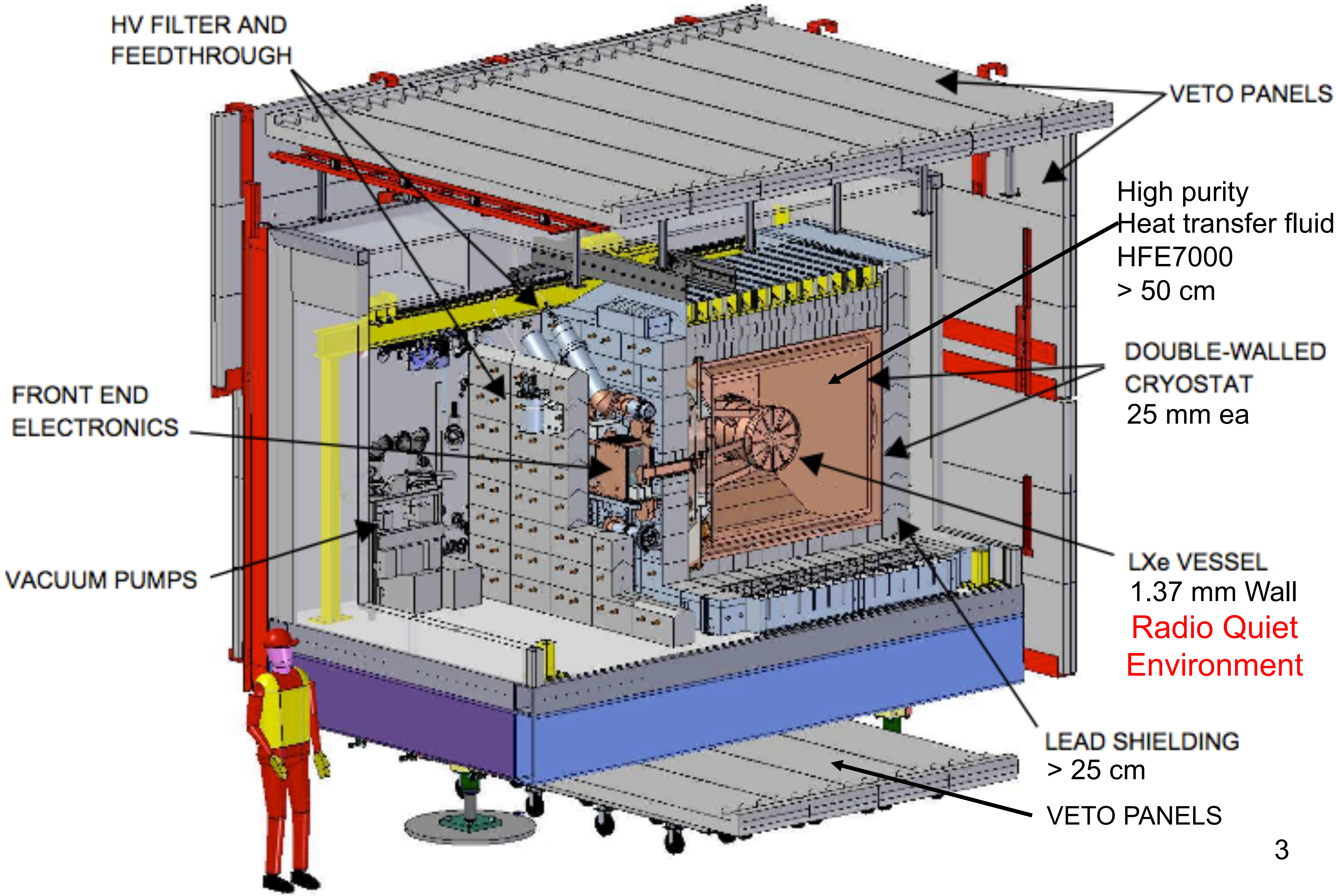


- Cherenkov light or scintillation to distinguish α from β/γ ($^{130}TeO_2$, $Zn^{82}Se$, $^{116}CdWO_4$, and $Zn^{100}MoO_4$)
- More rejection power needed: 99.9% α background suppression. Light detector R&D for better resolution.
  - –R&D on TES in US
  - –R&D on MKID in Italy
  - –R&D on NTD/Luke effect in France/LNGS
- Background free search.

$$m_{\beta\beta} \sim (M \cdot t)^{-1/2}, \text{not } (M \cdot t)^{-1/4}$$



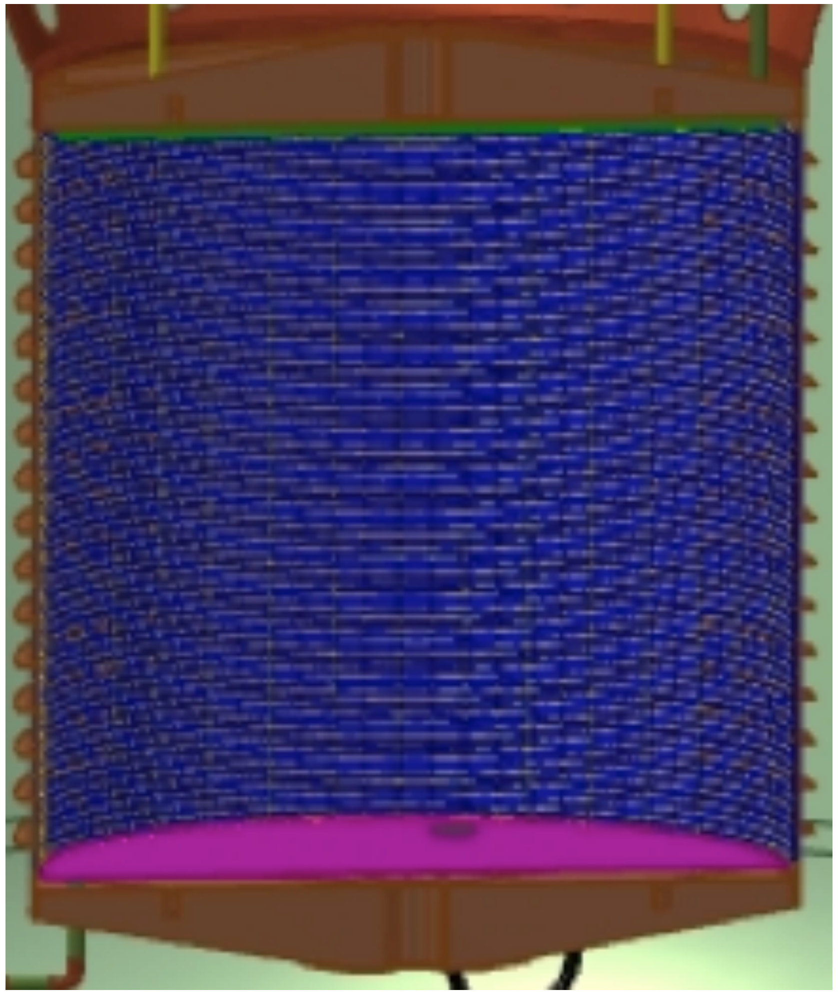
The EXO-200 Detector



From EXO-200 to nEXO Detector

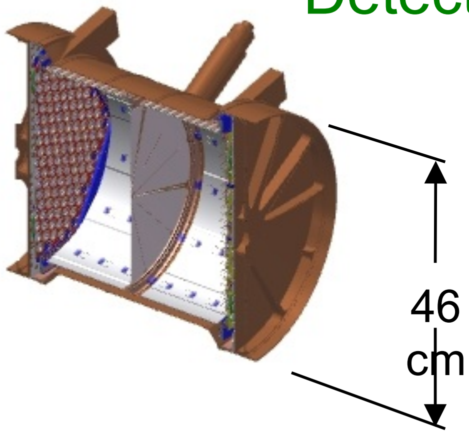
- **EXO-200 have achieved design energy resolution, background goal and SS/MS rejection capability.**
- nEXO is a 5 tonne LXe TPC with better detector performance, *initially* without Ba-tagging.
- 4.7 tonnes of active ^{enr}Xe (80% or higher), < 1.0% (σ) energy resolution.
- Assuming observed EXO-200 backgrounds. $\beta\beta$ scales like the volume, most backgrounds scale like the surface area.

1.3 m

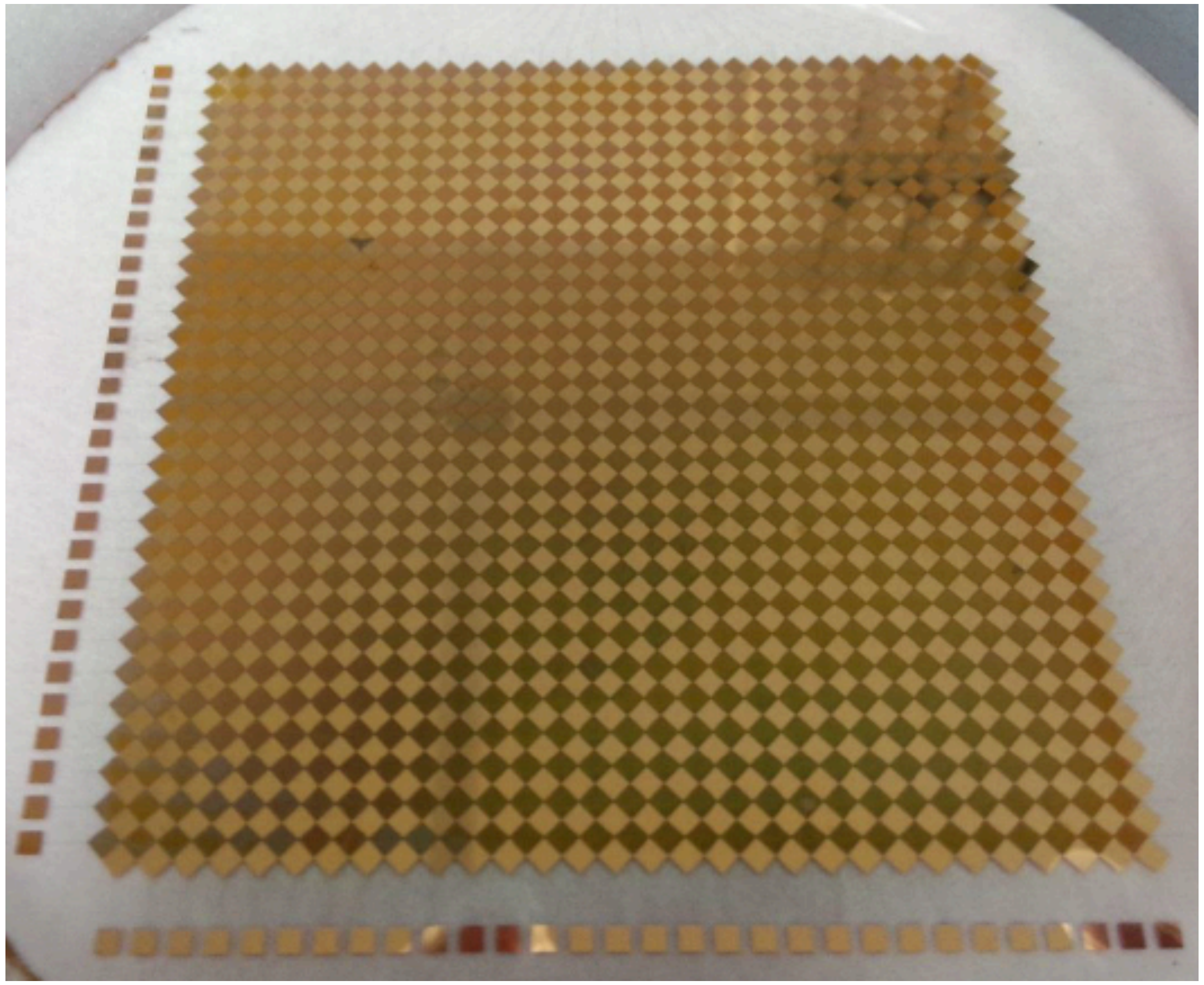


nEXO Detector

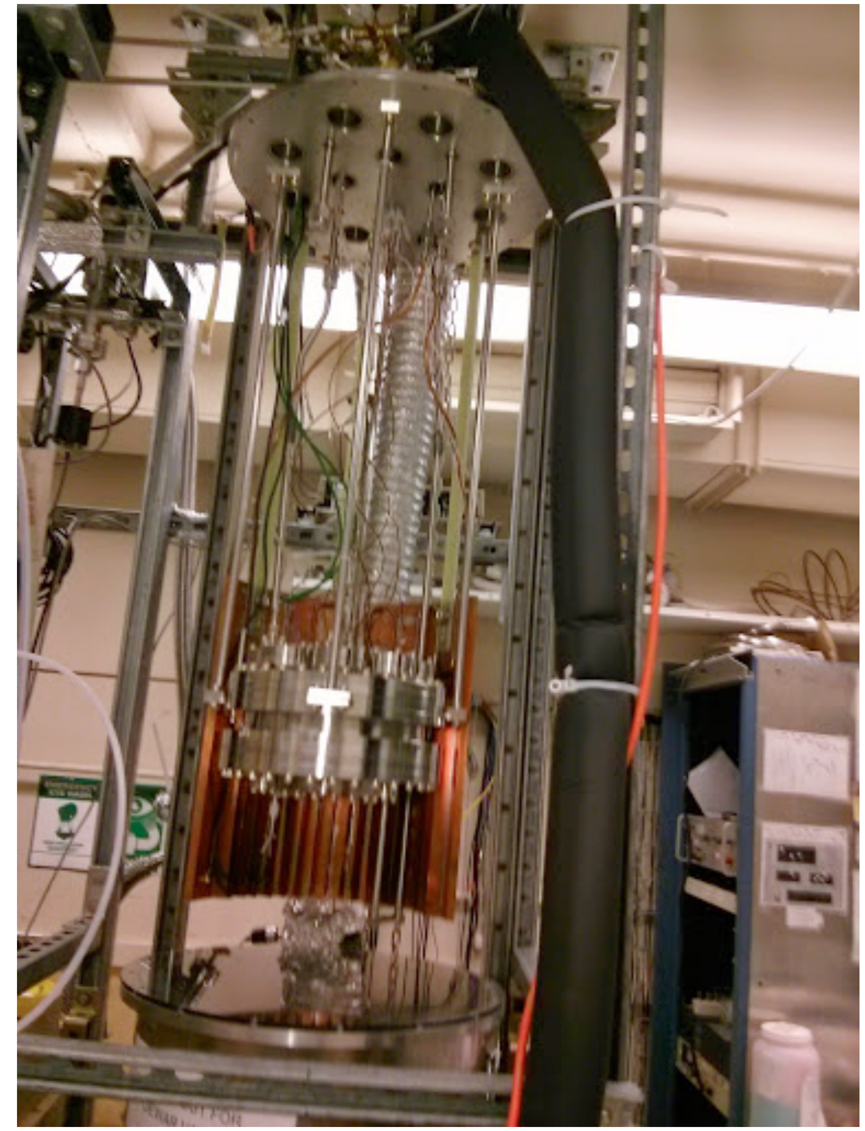
EXO-200 Detector



Charge Collection Tiles



Prototype Charge Readout Quartz Tile



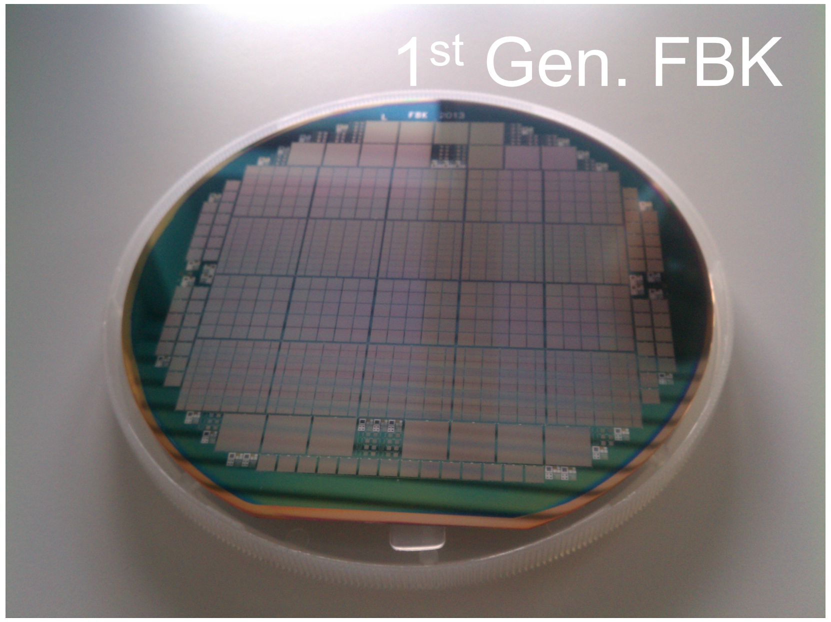
Charge Readout LXe test apparatus

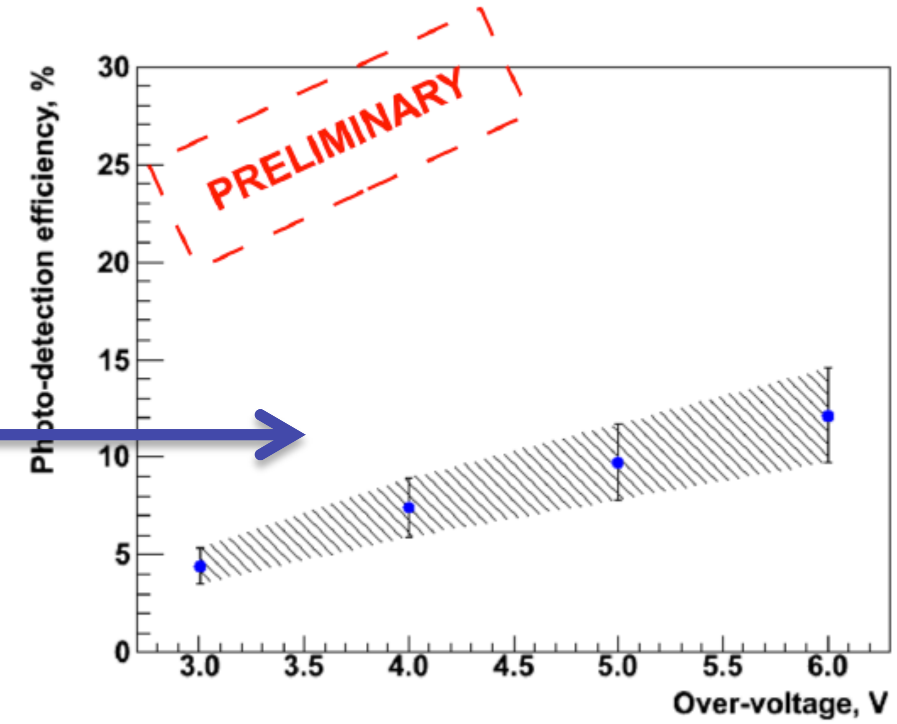
- **Improve ββ and gamma discrimination**
- **Lower background from readout structures**

R&D activities:

- Develop charge readout structures on low background substrates.
- Simulate and measure charge collection in LXe and SS/MS discrimination.

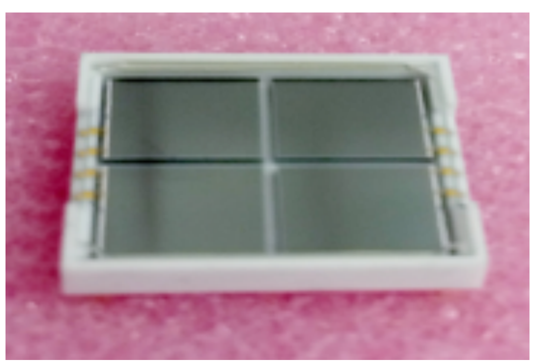
UV Sensitive SiPM

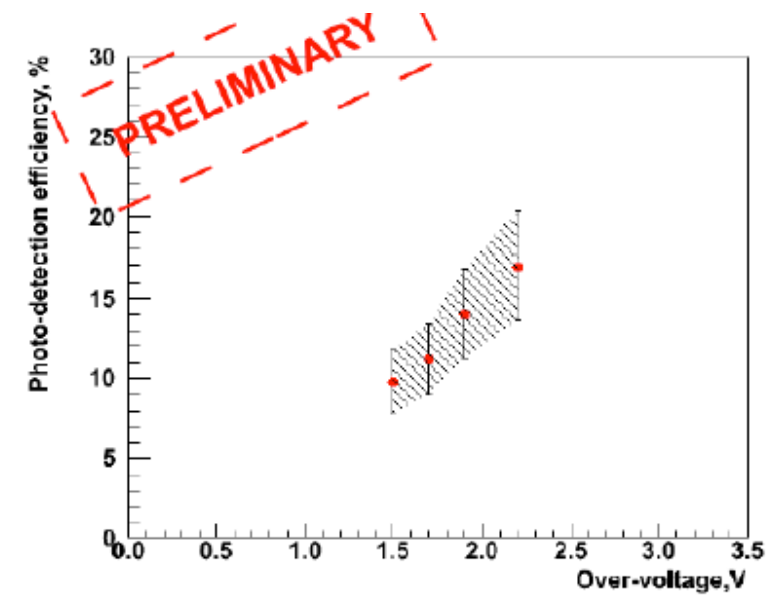




2nd Gen. FBK has improved performance.

Hamamatsu MEG device





Need low background packaging

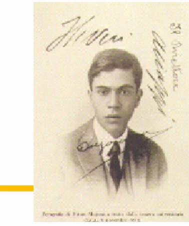
- **Higher light collection efficiency.**
- **Lower background photo-sensor.**

Photon Detection Efficiency Measurements

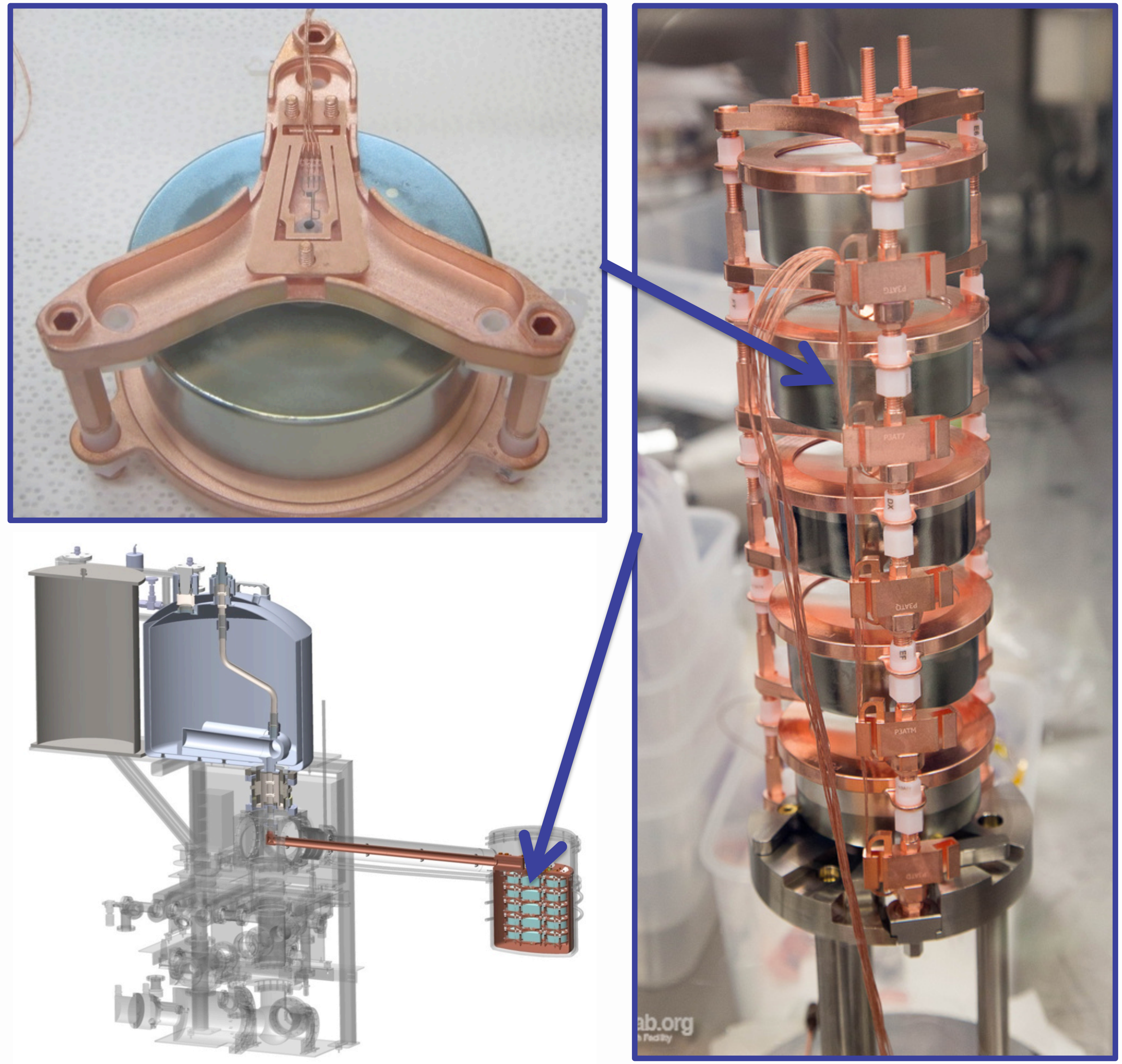
R&D activities:

- Develop SiPMs with > 15% photon detection efficiency for 180 nm light.
- Determine the intrinsic radio-purity of SiPM.

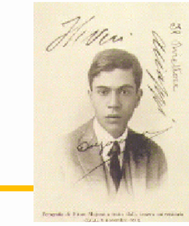
MJD Detector Array Overview

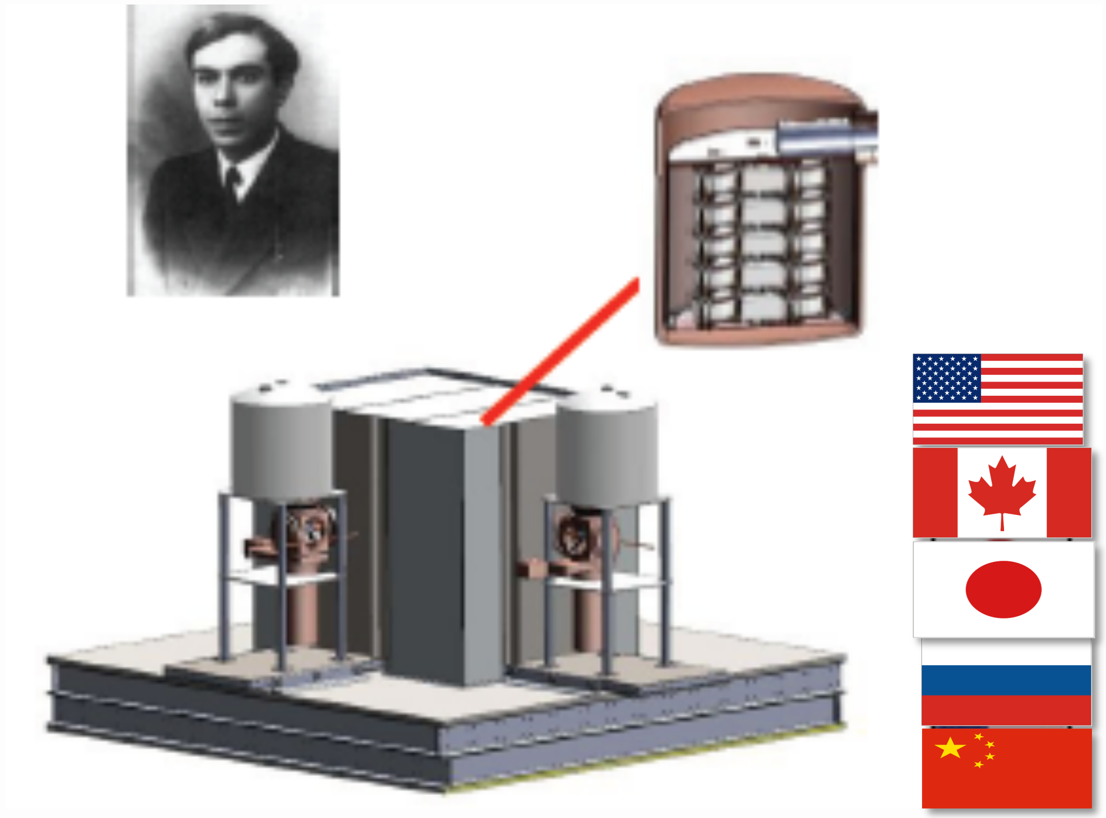


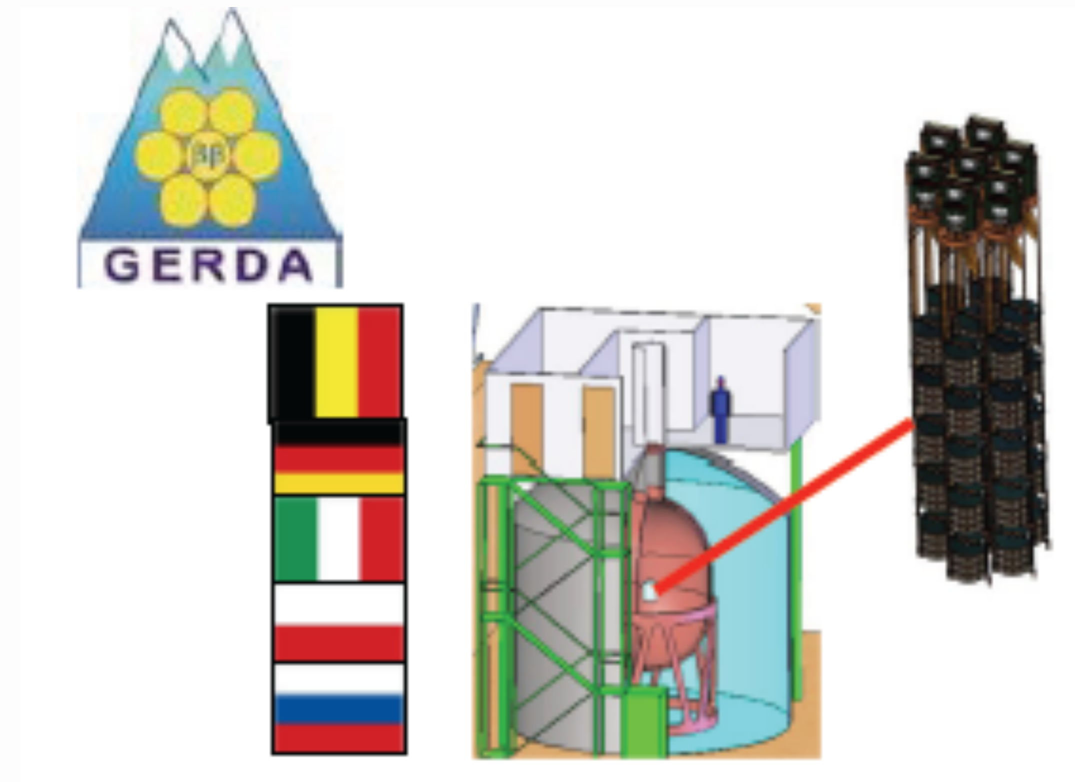
- Detector Units
  - Low mass PPC detector mounting structure
  - Adaptable to a range of form factors
  - Copper and PTFE construction
- Stacked into “Strings” of 4-5 detectors
- Modular Cryostats:
  - Capacity: 7 strings, up to 22.5kg
  - Form factor driven by compact shielding capability
  - Demonstrated operation in 2 cooling configurations:
    - Thermosyphon
    - Pulse-tube cooler



MAJORANA DEMONSTRATOR and GERDA







- ^{76}Ge modules in electroformed Cu cryostat, Cu / Pb passive shield
- 4π plastic scintillator μ veto
- DEMONSTRATOR: 30 kg ^{76}Ge and 10 kg ^{nat}Ge PPC detectors

- ^{76}Ge array submersed in LAr
- Water Cherenkov μ veto
- Phase I: ~18 kg (H-M/IGEX xtals)
- Phase II: +20 kg PPC detectors

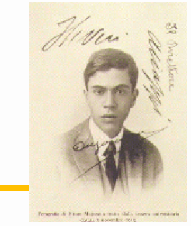
Joint Cooperative Agreement:

Open exchange of knowledge & technologies (e.g. MaGe, R&D)

Intention to merge for larger scale experiment

Select best techniques developed and tested in GERDA and MAJORANA

Large-Scale R&D Efforts



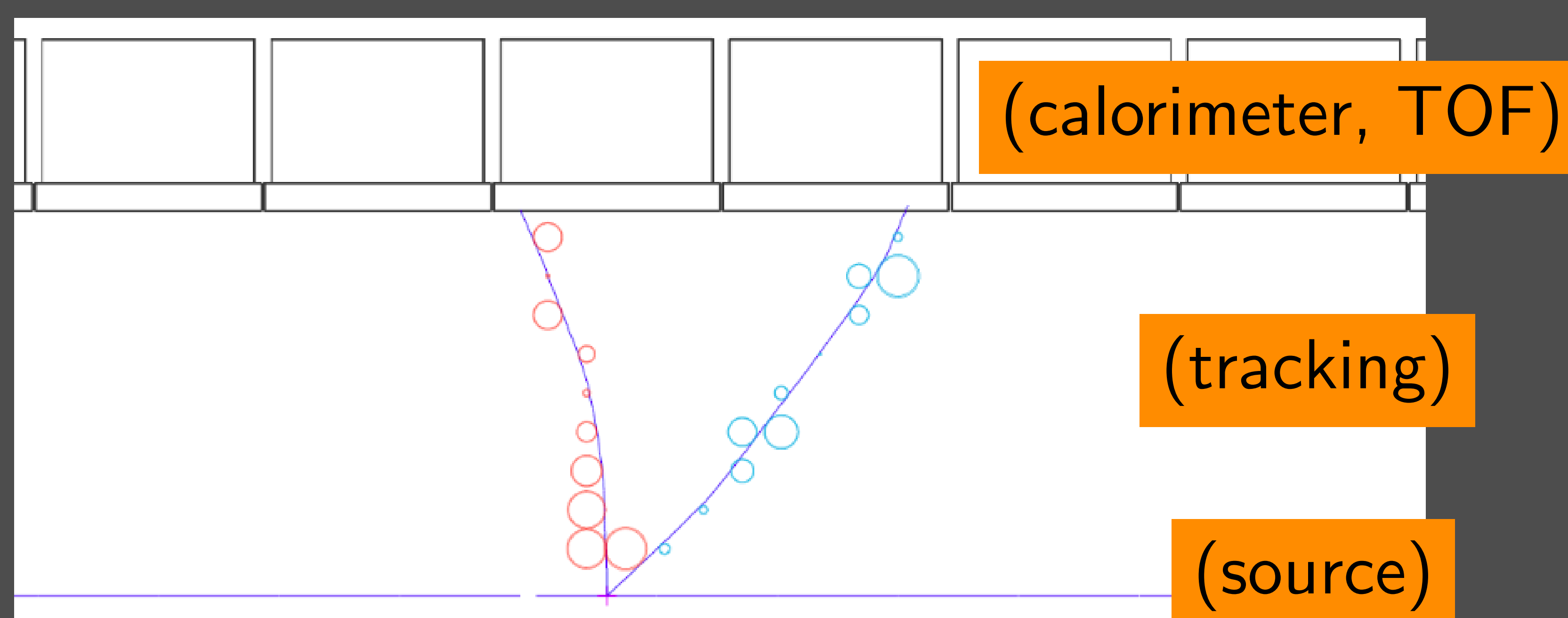
Several areas of needed R&D for a tonne-scale experiment have been identified and will be explored over the next several years.

- Ge Detector Development
  - Large detectors
  - Field shaping geometries
  - Small contacts
  - Ge recovery and reprocessing
- Detector Assemblies
  - Additive manufacturing
  - Cables & connectors
- Materials & Assay
  - Improved copper assay
  - Improved electroforming methods
  - New dielectrics
- Array Shielding
  - Instrumented liquid cryogen
  - Investigation of hybrid design
  - Alternative shield materials
    - Lead purification
    - Depleted germanium
- Simulations and Analysis
  - Background budgets
  - Neutron backgrounds
  - Required experimental depth
  - Shielding simulations
  - Radon-daughter backgrounds

A technically-constrained schedule would allow construction of a large-scale Ge $0\nu\beta\beta$ experiment to begin in 2018/2019.

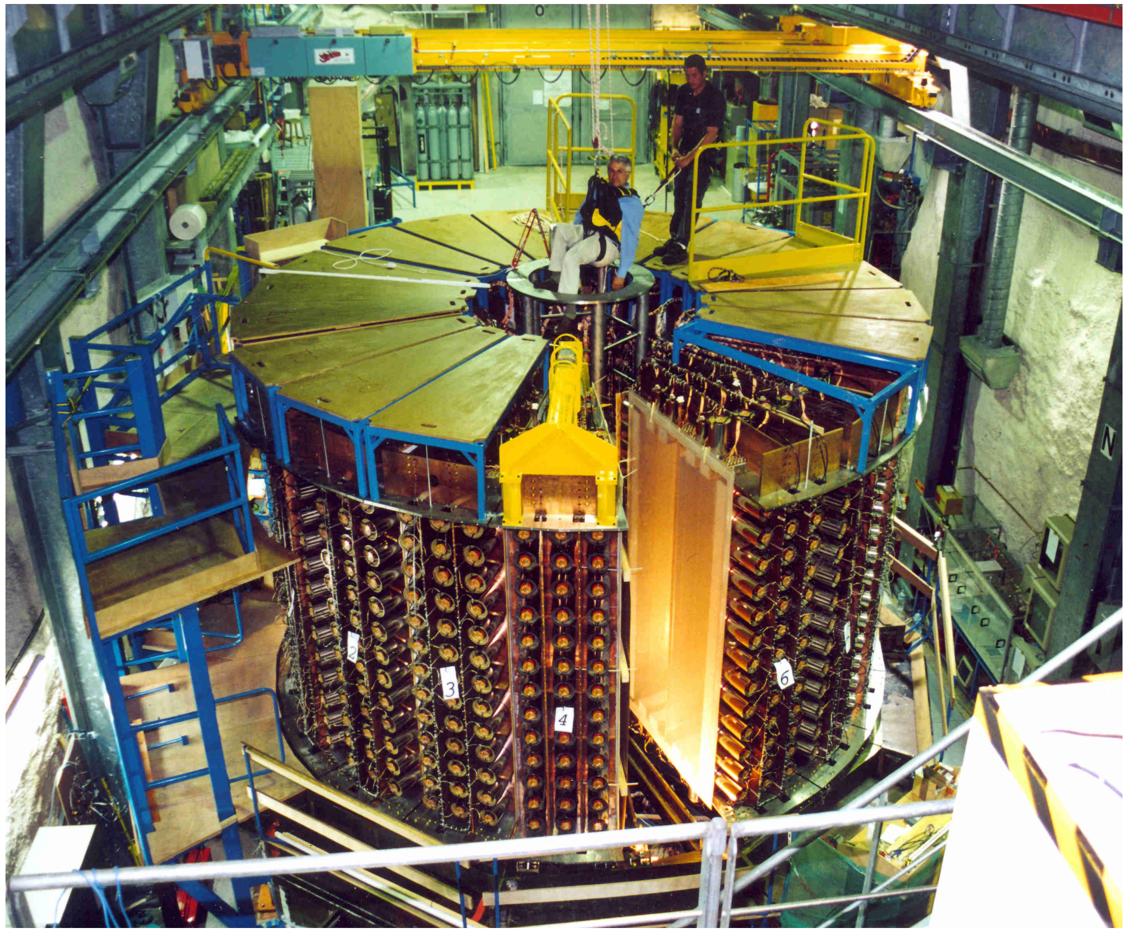
SuperNEMO in a nutshell

- physics goals:
  - primary: neutrinoless double beta decay ($0\nu2\beta$) of ^{82}Se
  - other:
    - $0\nu2\beta$ of ^{150}Nd and ^{48}Ca
    - $2\nu2\beta$ decays
    - decays to excited states
    - Majoron emission
    - related nuclear physics
- location: Modane Underground Laboratory (LSM), France, 4800 m.w.e.
- $\sim$100 collaborators
- detector concept:



NEMO-3: The Neutrino Ettore Majorana Observatory

- Located in the *Laboratoire Souterrain de Modane* (LSM) in the French Alps under 4800 m.w.e.
- Shielded by 30 cm of borated water or wood, 19 cm of steel and radon-free air tent (2004)



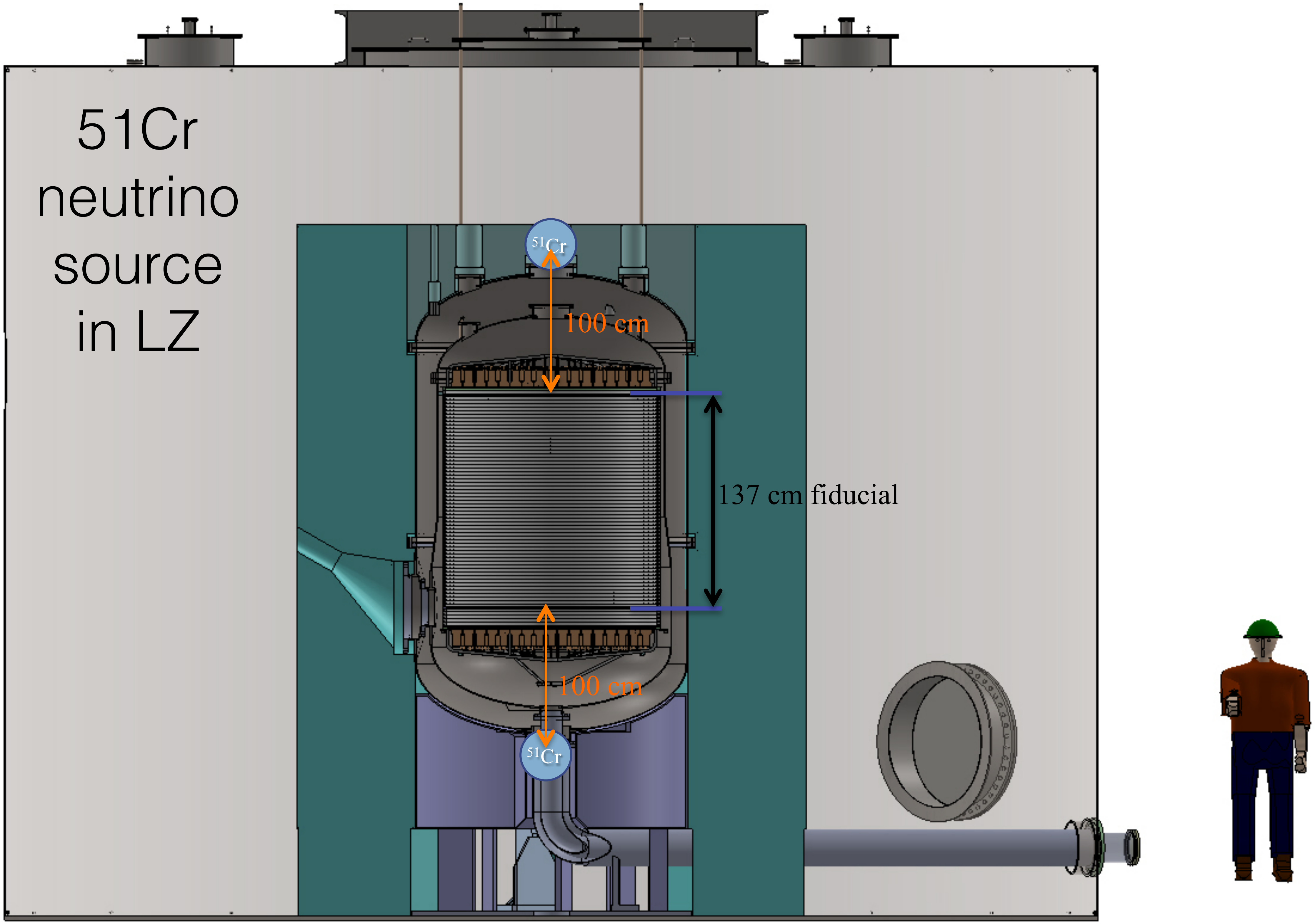
Phase 1
Feb. 2003 - Oct. 2004
$\mathcal{A}_{\text{int}}(^{222}\text{Rn}) \sim 30\ \text{mBq/m}^3$

Phase 2
Dec. 2004 - Jan. 2011
$\mathcal{A}_{\text{int}}(^{222}\text{Rn}) \sim 5\ \text{mBq/m}^3$

We’re on track to detect coherent neutrinos in a few years with inexpensive hardware

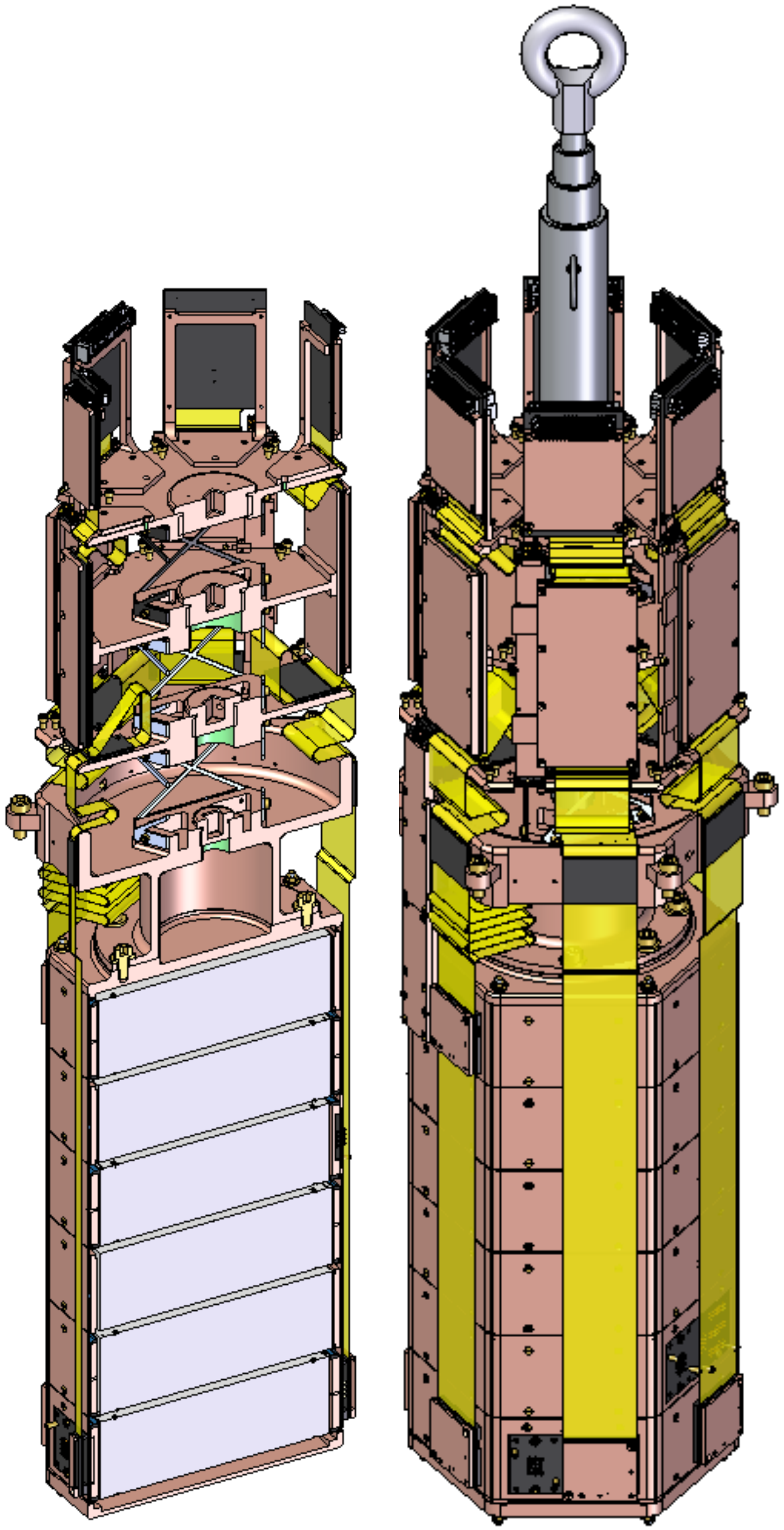
- Ricochet: ex-CDMS hardware —> reactor
- COHERENT: ex-Majorana, Chicago CsI, Moscow Xe TPC —-> Oak Ridge SNS
- CR51: LZ experiment <—- 51Cr source (neutrino magnetic moment)

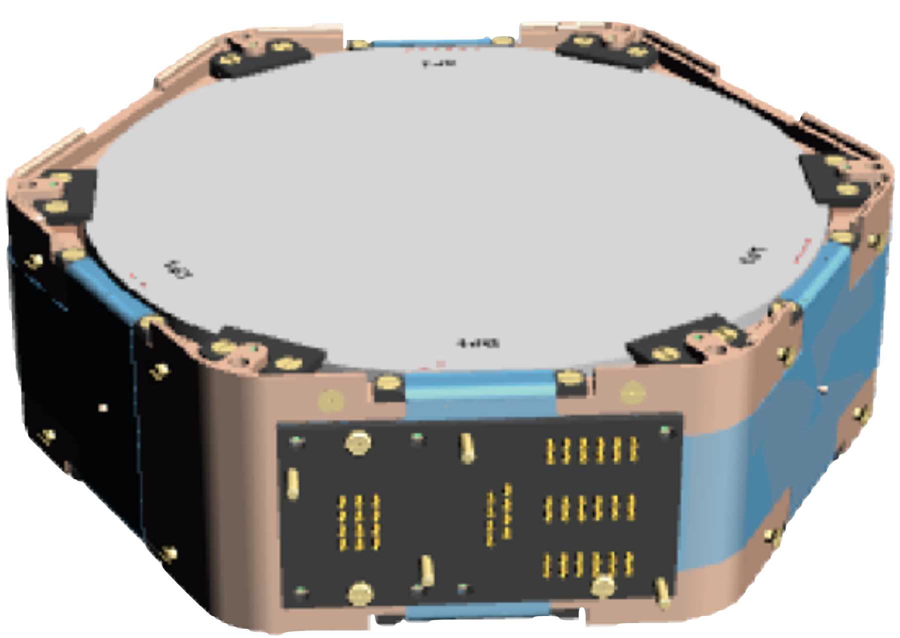
Alternate Implementations



Ricochet Phase 1: SuperCDMS Tower at a Reactor

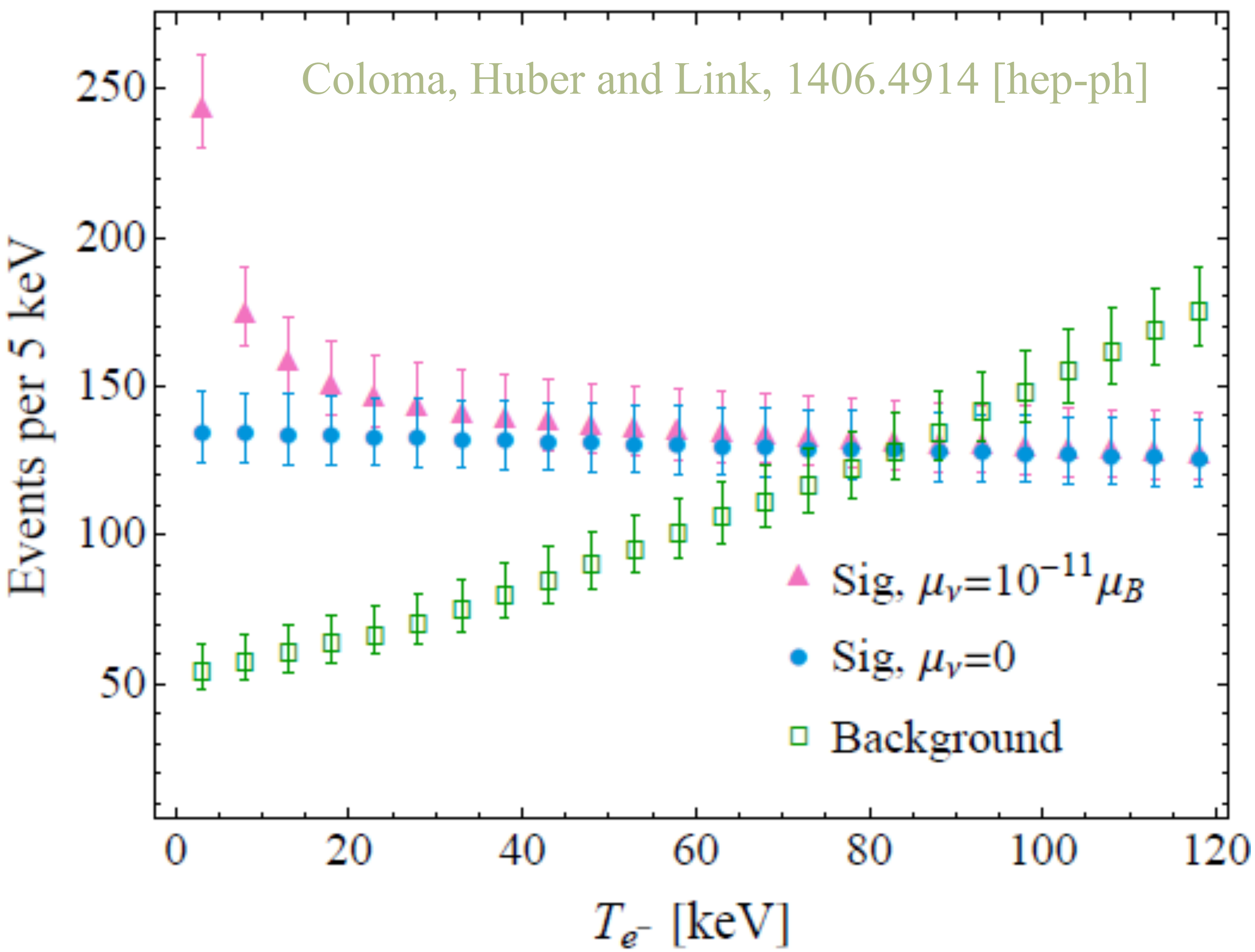
- Leverage R&D and Engineering being done by the SuperCDMS G2 Experiment.
- 1 Tower holds 6 detectors, ~100 eVnr Threshold
- 4 Si Detectors = 2.4kg Si = 11 CE**v**NS events per day
- 2 Ge Detectors = 2.8kg Ge = 26 CE**v**NS events per day
- **>7000/1000/400** events per month at the SONGS, ATR, and MIT reactors
- **>20** events per month at the SNS (for comparison)





Calculation of Elastic Scattering Rate in LZ

Assuming an exposure of 100 days from a single 5 MCi source (5.8×10^{23} emitted neutrinos), and the source center located 1 m from the edge of the fiducial volume.



The expected number of weak interaction events is ~12,500.

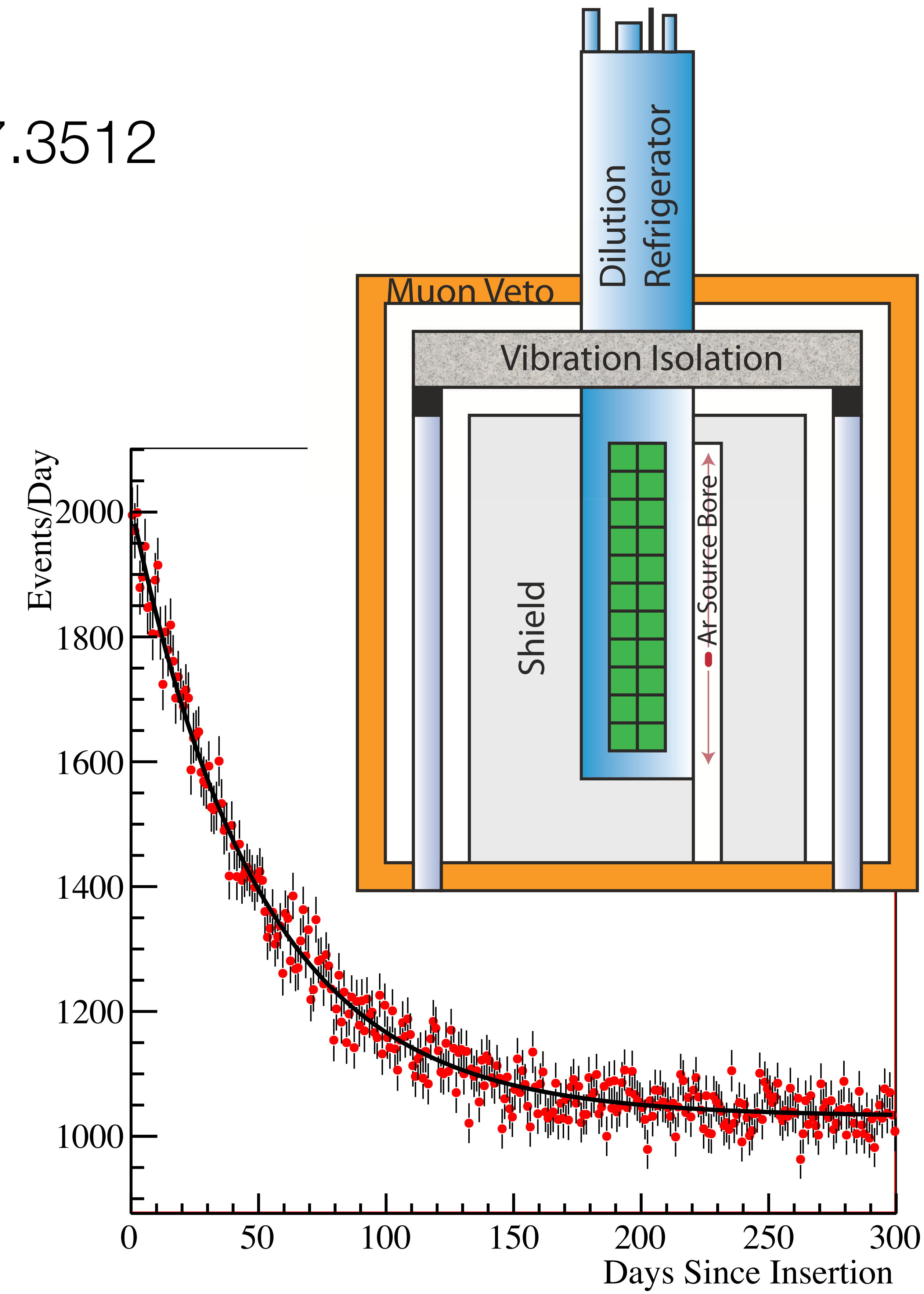
At the Gemma limit, E&M interactions would add more than 3,000 events.

A huge enhancement at low recoil energy

Ricochet Phase 2: CEνNS with ~1 MeV neutrinos

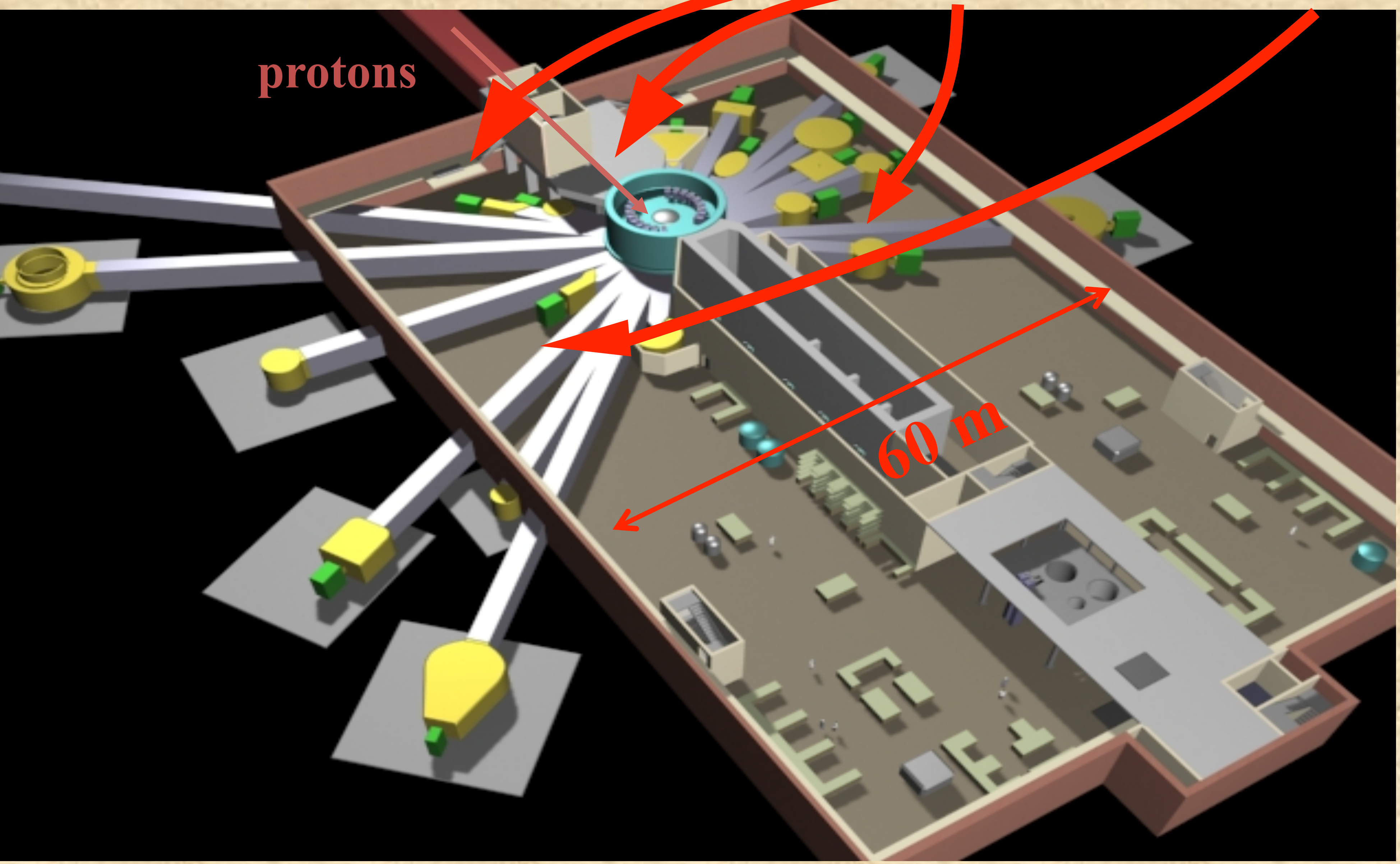
arXiv:1107.3512

- Array of 10,000 elements with ^{37}Ar or ^{51}Cr source just outside shield (10 cm closest distance).
- Measuring time of 300 days (for ^{37}Ar, equivalent of 50 days signal, 250 days background).
- Background rate of 1 event/kg/day in energy region of interest
- R&D needed, would be a "smoking gun" experiment done if charged current experiments saw a signal.



Potential Locations for Neutrino Experiment at the SNS

sites inside target building including basement



Multiple sites are available at a distance 15-20 m.

“Green field” is outside of the target building for distances more than 30 m

ORNL is strongly supporting BG studies for neutrino experiment at the SNS

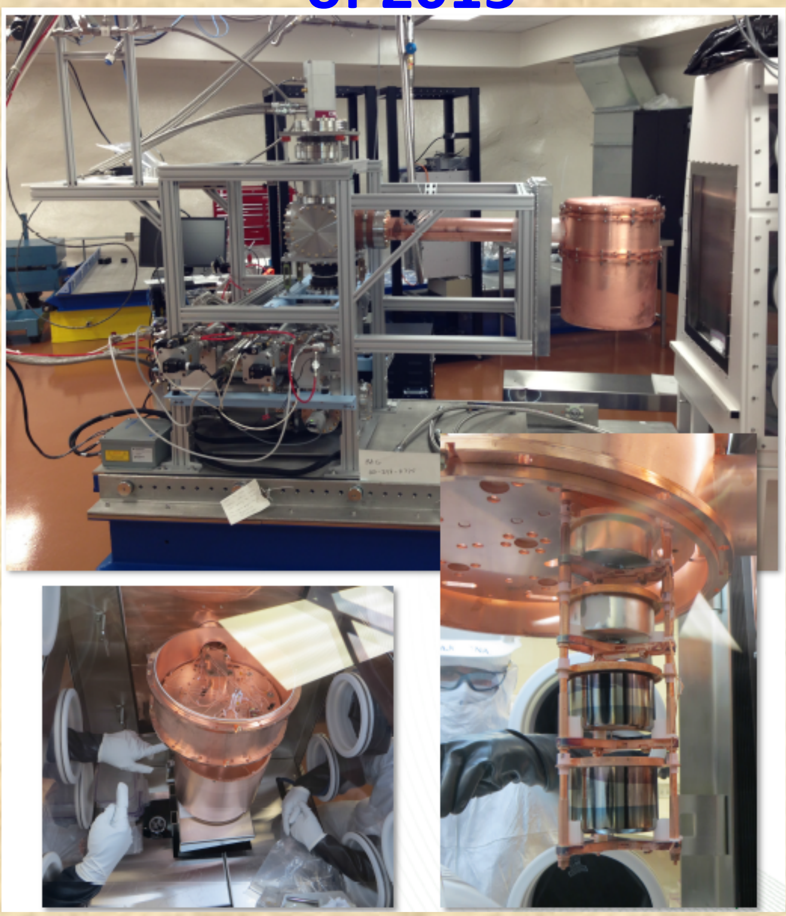
ORNL support: 3 LDRD’s (>$300k) + Wigner Fellow

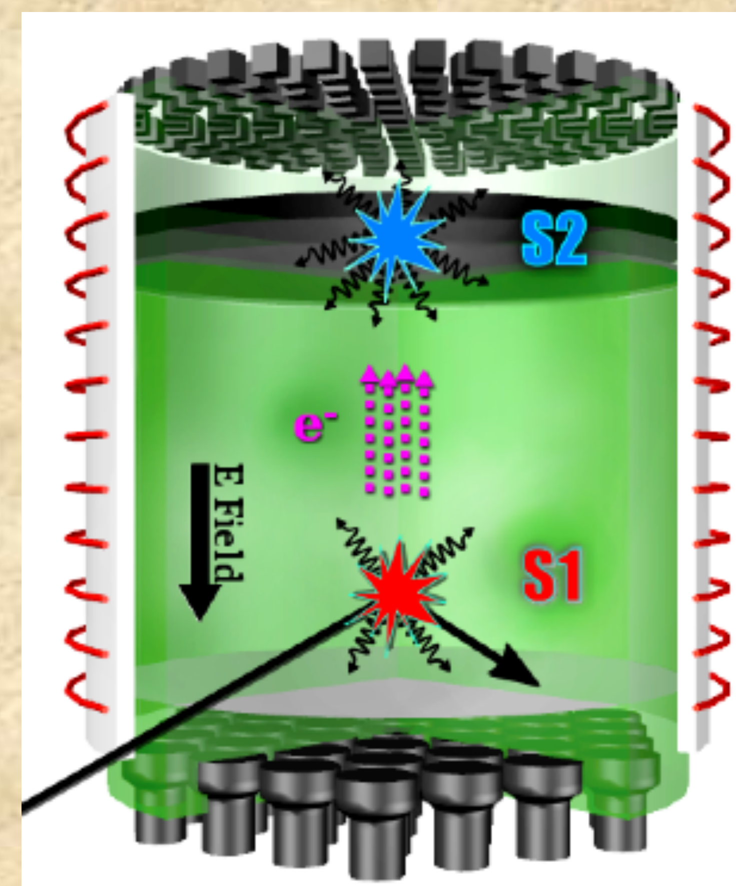
Three detector technologies are "Ready"

MJD prototype cryostat with 20 kg of HPGe detectors, could be available by the end of 2015

14 kg low background CsI crystal is available at the University of Chicago

100 kg, 2 phase LXe is detector being built at MEPhI, Moscow





15 m from the target, 100 kg detector, prompt 30 MeV neutrinos

Target	Max Recoil (keV)	Cross section $10^{-42}cm^2$	Threshold, keV_{nr}	N events, year
Ge	27	5830	3	2560
I	15	19400	10	732
Xe	15	22300	1	5970

Unified R&D wish list

- Liquid noble gases: general need for reliable high-voltage design principles. EXO (!) NEXT (?), in common with dark matter and long baselines.
  - Experience of "things that work on test stand but spark when installed."
- Low-background everything
  - Copper (Majorana, CUORE), cabling (CUORE)
- New and complex scintillators (Kamland-Zen, SNO+, Theia, NuDot) and matched photosensors (fast? cheap? red-sensitive?)

OK, this is not unified